Feasibility of composing green mountain pine beetle veneers

Chunping Dai, Guangbo He, Heng Xu

Mountain Pine Beetle Working Paper 2009-09

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Abstract

When mountain pine beetle logs are used to manufacture plywood and laminated-veneer lumber, veneer recovery can drop by 30%. Veneer composing is an effective and efficient way to improve veneer recovery, and the lower moisture content of mountain pine beetle veneers makes composing green veneers feasible and advantageous. This project studied the feasibility of composing green mountain pine beetle veneers using three gluing methods: taping, string-gluing, and fibre-gluing. Adhesive screening using the automated bond evaluation system indicated that a two-part polyurethane/emulsion polymer adhesive gave the highest bond strength, the highest curing speed, and the highest moisture tolerance. A one-part polyurethane adhesive showed relatively high moisture tolerance, but with lower bond strength and curing speed than the polyurethane/emulsion polymer adhesive. Green veneer composing by taping with the polyurethane adhesive was successful with veneer moisture content up to 60%. String-gluing with the polymer adhesive was also successful with moisture content up to 60% and with a shorter press time. Fibre-gluing was successful with the moisture content up to 40%.

Shrinkage of composed veneers after drying was up to 2 mm for the veneer composed by taping and fibre-gluing, and over 2 mm by string-gluing. This gap may affect the quality of composed veneers. In general, green veneer composed by gluing was successful under appropriate conditions.

Green veneer composing may improve mountain pine beetle veneer recovery by 20 %, improve drying efficiency, and reduce labour, saving up to $4.5 million per year for an average mill. Green veneers can be composed in current plywood mills with minor modifications to conventional dry-veneer composing.

Keywords: mountain pine beetle, green veneer composing, adhesive

Résumé

Lorsque des grumes attaquées par le dendroctone du pin ponderosa (DPP) sont utilisées pour fabriquer du contreplaqué et du bois en placage stratifié (LVL), la récupération du bois de placage peut baisser de 30 %. L'assemblage de bois de placage est une manière efficace et rentable d'améliorer la récupération du bois de placage, et l'humidité relativement faible du bois de placage attaqué par le DPP rend l'assemblage du bois au stade vert réalisable et avantageux. Le présent projet étudiait la viabilité de l'assemblage de bois de placage obtenu de billes attaquées par le DPP au stade vert, réalisé au moyen de trois méthodes de collage : collage par ruban adhésif, par cordons de colle et par collage des fibres. Selon l'analyse de l'adhésif au moyen du système d'évaluation automatisé de la liaison, un adhésif combiné polyuréthanne/polymère en émulsion (PU-ISO) donnait la résistance d'adhésion la plus élevée, la vitesse de polymérisation la plus rapide et la tolérance à l'humidité la plus haute. Un adhésif polyuréthanne simple (PU-PL) a montré une tolérance à l'humidité relativement élevée, mais avec une résistance d'adhésion et vitesse de polymérisation plus faibles que l'adhésif PU-ISO. L'assemblage de bois de placage au stade vert au moyen de ruban adhésif PU-PL a fonctionné avec du bois de placage ayant une humidité allant jusqu'à 60 %. L'assemblage de bois de placage par cordons de colle PU-ISO a également réussi avec une humidité allant jusqu'à 60 % et un temps de presse plus court. L'assemblage de bois de placage par collage des fibres a fonctionné avec une humidité allant jusqu'à 40 %.

Un rétrécissement des assemblages a été constaté après le séchage. L'écart pouvait atteindre 2 mm pour les assemblages collés par ruban adhésif et par cordons, et était supérieur à 2 mm en cas de collage des fibres. Un tel écart peut nuire à la qualité du placage assemblé. En général, l'assemblage de bois de placage au stade vert par collage a été un succès lorsque les conditions étaient appropriées.

Une analyse économique a montré que l'assemblage de bois de placage au stade vert pouvait améliorer de 20 % la récupération du bois de placage attaqué par le DPP, augmenter l'efficacité du séchage et épargner du travail, pour un total de 4,5 M$ d'économies annuelles pour une usine de taille moyenne. Les bois de placage au stade vert peuvent être assemblés dans les usines de contreplaqués actuelles, en adaptant légèrement le procédé d'assemblage classique de bois de placage sec.

Mots clés : dendroctone du pin ponderosa, assemblage de bois de placage au stade vert, adhésif

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1 Introduction

Using green/red stage mountain pine beetle (MPB) wood reduces plywood recovery by 8% (Wang and Dai 2004), and using grey stage wood drops recovery by 30% (Snellgrove and Ernst 1983). These studies demonstrated that the biggest impact of using MPB wood for veneers is low fibre recovery, due primarily to making excess partial (random) veneer sheets instead of full veneer sheets (4 × 8 ft). Random sheets also significantly reduce dryer productivity and cause handling problems in plywood/laminated-veneer lumber (LVL) production. Therefore, finding a way to produce full sheets is critical to the viable use of MPB wood for veneer production.

Given the dry and cracked nature of MPB logs, there is little or no hope of preventing the generation of random sheets at the peeling lathe. As a common practice in the industry, veneer composing (a process which pieces random sheets into full sheets) only takes place after veneer drying. Current veneer composing methods only work with dry veneers. Handling efficiency, dryer productivity, and fibre recovery can increase significantly if veneer is composed before drying. With the MPB veneers already significantly drier than typical green veneers, it is now possible to look into composing *green* veneer.

Current technologies for veneer composing include gluing, stitching, and hot-pressing. Gluing is rapid and effective, and it has the least negative impact on the mechanical properties of composed veneers. Traditional veneer composing uses hot-melt adhesives for bonding random-veneer sheets into full-veneer sheets. However, hot-melt adhesives are not suitable for green veneers because after composing, green veneers are dried at a high temperature, which melts the adhesive and reverses composing. Therefore, finding appropriate thermosetting adhesives that can bear high temperatures after curing is crucial for the successful composing of green veneer by gluing.

The objectives of this project were to determine the feasibility of composing green MPB veneers before drying, and the economics of composing green MPB veneers in plywood/LVL mills. Four thermosetting resins were screened using an automated bond evaluation system (ABES) and two of them were selected for green veneer composing by gluing. Mountain pine beetle veneers were composed by various methods, such as taping, string-gluing, and fibre-gluing. Composed veneers were dried at a high temperature. An economic analysis was conducted on green MPB veneer composing in plywood/LVL mills.

2 Materials

Adhesives applied to green-veneer composing by gluing can only be selected from thermosetting resins, as they minimize the effect of high temperature on bond strength. Furthermore, the selected adhesives must be capable of bonding wet veneers because green MPB veneers still have up to 40% moisture content (MC). Also, adhesive curing speed is important for veneer composing productivity. With these requirements, the following four resins were selected for screening tests:

- a one-part polyurethane construction adhesive (PU-PL),
- a two-part polyurethane/emulsion polymer adhesive (PU-ISO),
- a phenol-resorcinol-formaldehyde adhesive (PRF), and
- a phenol-formaldehyde plywood adhesive (PF).

Dried-MPB veneers (thickness 3.2 mm, average MC 7%) and green MPB veneers (thickness 3.2 mm, average MC 20%-50%) were obtained from FPInnovations–Forintek members' mills. For adhesive screening, MPB veneers were sliced 0.8 mm thick and cut into 100 mm x 20 mm strands for ABES testing. The following materials were also used in veneer composing:

Kraft paper: 70 g/m^2 (weight), 0.07 mm (thickness)

Glass-fiber string: 1.3×10^{-4} kg/m (weight)

Short-glass fiber: 5 mm (length)

3 Methods

3.1 Tests for Adhesive Screening

Adhesives were screened by testing the shear-bond strength between two MPB strands bonded with a selected adhesive using an automated bond estimation system (ABES) in the Forintek laboratory. A MPB strand was coated with an adhesive and bonded to another strand. The bonding pair was hot-pressed to cure the resin, then pulled apart to evaluate the shear bond strength. The tests were carried out with three press temperatures and four press times for each adhesive. Ten specimens were tested for each condition.

Test strands were adjusted to different moisture contents (MC) to evaluate the bonding performance of selected adhesives under high MC. To obtain MPB strands with high MC, dry MPB strands were soaked in water for two hours, and dried in the air until reaching the target MC. The strands were kept in a sealed plastic bag and stored for at least 12 hours before being tested.

The conditions of the screening tests are tabulated in Table 1. The low MC of the strands was set at 20%, which reflected the MC of grey-stage MPB logs (Feng and Knudson 2007). Press temperatures used in the tests matched the range of the wood-composite manufacture. Press time ranged from 10 s to 2 min. The short press time was used to estimate the resin curing speed and the long press time to determine the ultimate bond strength.

Table 1. Testing conditions for adhesive screening.

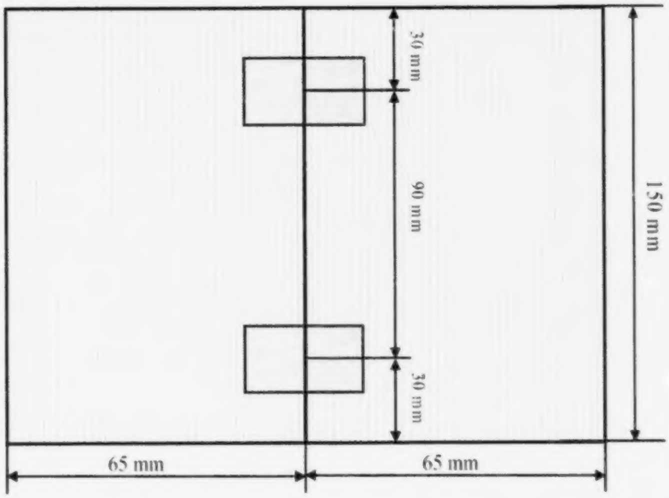
Strand dimensions (mm)	100 × 20 × 0.8
Strand MC (%)	20, 30, 45
Resin solids loading (mg/cm^2)	4.0
Overlap area (mm^2)	100
Press temperature (°C)	120, 150, 200
Press time (s)	10, 30, 60, 120
Replicates	5

3.2 Green Veneer Composing by Gluing

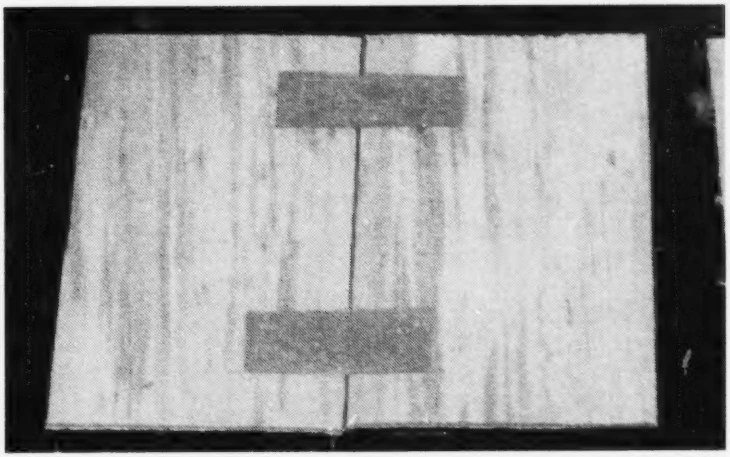
Mountain pine beetle veneers were cut into 150 mm × 65 mm pieces and conditioned to target MC before composing. Veneers requiring a high target MC of over 20% were soaked in water under a vacuum-pressure cycle for 20 min and placed in a conditioning room until dried to the target MC. The veneers were sealed in a plastic bag until composing.

Three methods of green-veneer composing by gluing were used and evaluated: taping, string-gluing and fibre-gluing. For the taping method, the PU-PL resin was coated on one side of 20×40-mm kraft paper to form a piece of tape. Two pieces of tape were used to compose two 150×65-mm veneers into one. After

the veneer composing assembly, a hot iron heated to 170°C was manually pressed on the tape for 15 s for resin curing. A diagram and a sample of veneer composing by taping are shown in Figure 1.



Diagram



(B) Sample

Figure 1. (A) A diagram and (B) a sample of veneer composing by taping.

For the string-gluing method, glass-fibre string was coated with the PU-ISO resin at a 1.5 g/m resin-coating level. Two groups of glued string (two pieces of string in each group) were used to compose two 150×65-mm veneers into one by bonding two veneers across whole veneer surfaces as the conventional glue-string veneer composing does. After the veneer-composing assembly, a hot iron heated to 170°C was manually pressed on the string for resin curing. The press time was set at 5 and 10 s respectively for different samples. A sample of green-veneer composing by string-gluing is shown in Figure 2.

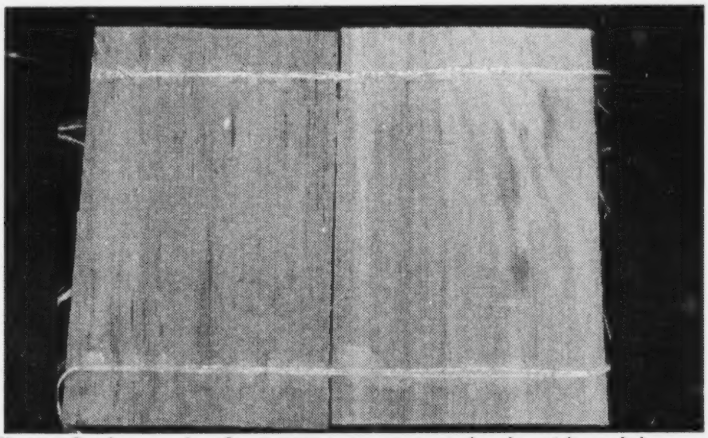


Figure 2. A sample of green-veneer composing by string-gluing.

For the fiber-gluing method, a measured amount of short-glass fiber was mixed in the PU-ISO resin to form a reinforced resin mixture. With two 150×65-mm veneers assembled, two drops of resin mixture were loaded on the joint line to replace the tape used in the taping method. The loading level of resin mixture was 0.5 g for each drop. After the veneer-composing assembly, a hot iron heated at 170°C was manually pressed on the drop of resin mixture for 10 s for resin curing. A sample of veneer composing with the reinforced resin mixture is shown in Figure 3.

The composed green veneers were evaluated by measuring the tensile performance against the bonding using an Instron machine, as shown in Figure 4. The crosshead speed was set at 5.5 mm/min.

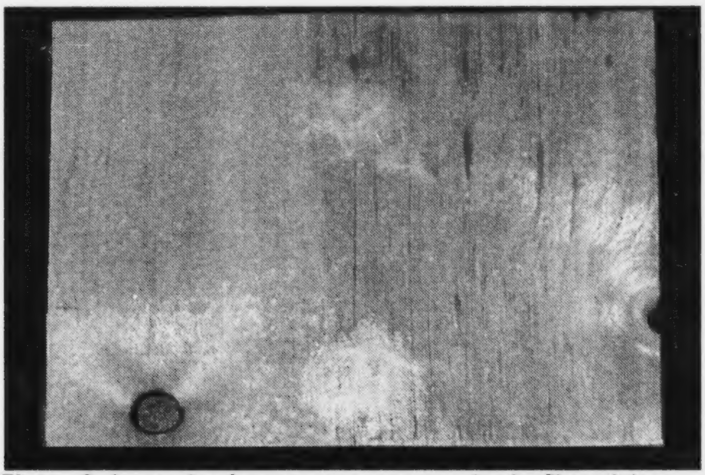


Figure 3. A sample of green-veneer composing by fibre-gluing.

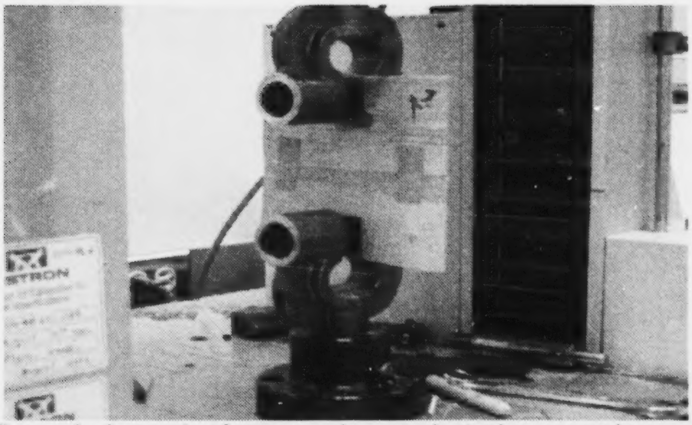


Figure 4. A sample of composed veneer by taping secured on Instron for tensile testing.

3.3 Drying of Composed-Green Veneers

Mountain pine beetle veneers measuring 300×100 mm were conditioned to the targeted MC. Veneer dimensions were measured before composing. Twelve composed veneers were made for each of the three methods described above. The composed veneers were dried in an oven at 180°C for various times until their final MC dropped to 0%–2%. The drying performance of composed veneers was evaluated by observing the dried veneers and measuring their dimensions.

4 Results

4.1 Screening of Selected Adhesives

Figures 5–8 show the bond performance of the four adhesives using 20% MC strands. At this low MC, all four adhesives gave good final bond strength with the highest values by PU-ISO resin and the lowest ones by PF resin. With the 10-second short press time, no bond strength was detected for PU-PL resin even at 200°C press temperature, but high bond strength > 5 MPa was formed for both PU-ISO and PRF resins. Only PRF resin produced high bond strength (> 5 MPa) at all three press temperatures with a 30-s press time, and 1.7 MPa bond strength at 150°C with a 10-s press time. This suggests that temperature may have the least influence on the curing speed of PRF resin among the four selected adhesives.

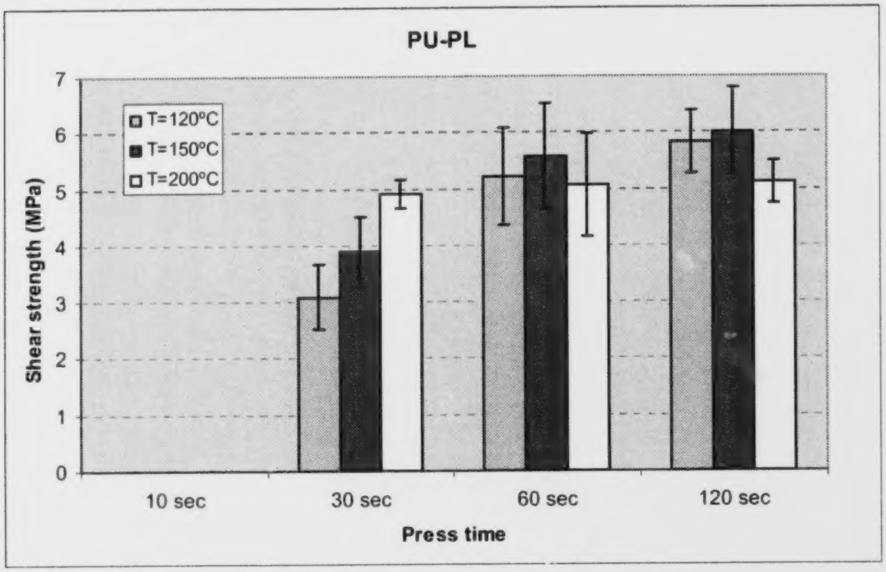


Figure 5. Bond strength of PU-PL adhesive using 20% MC strands.

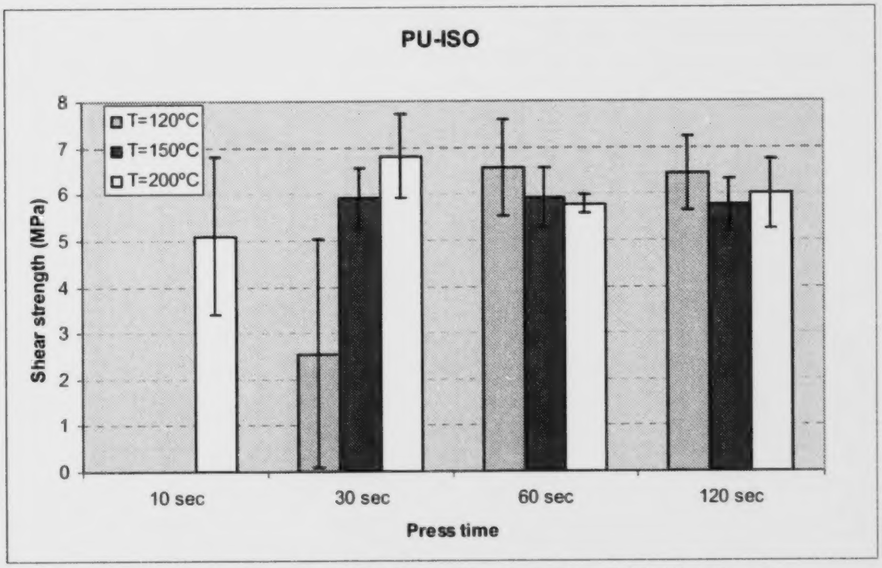


Figure 6. Bond strength of PU-ISO adhesive using 20% MC strands.

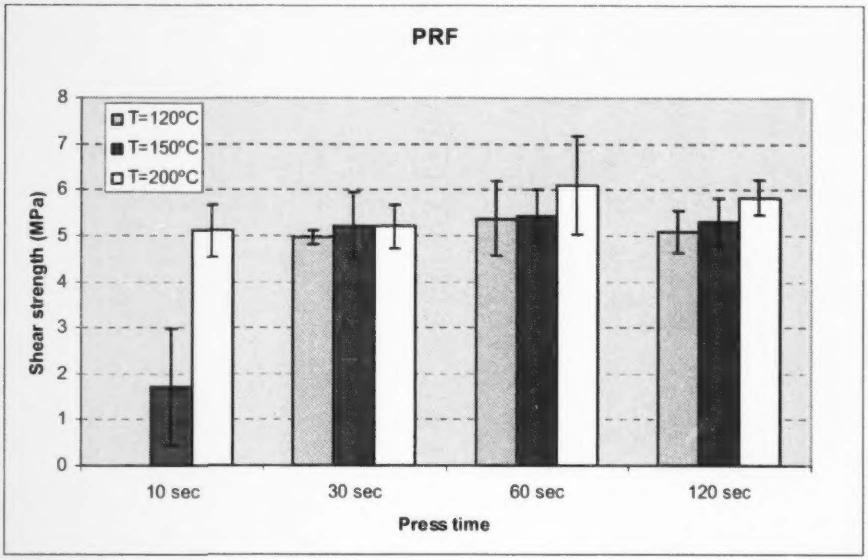


Figure 7. Bond strength of PRF adhesive using 20% MC strands.

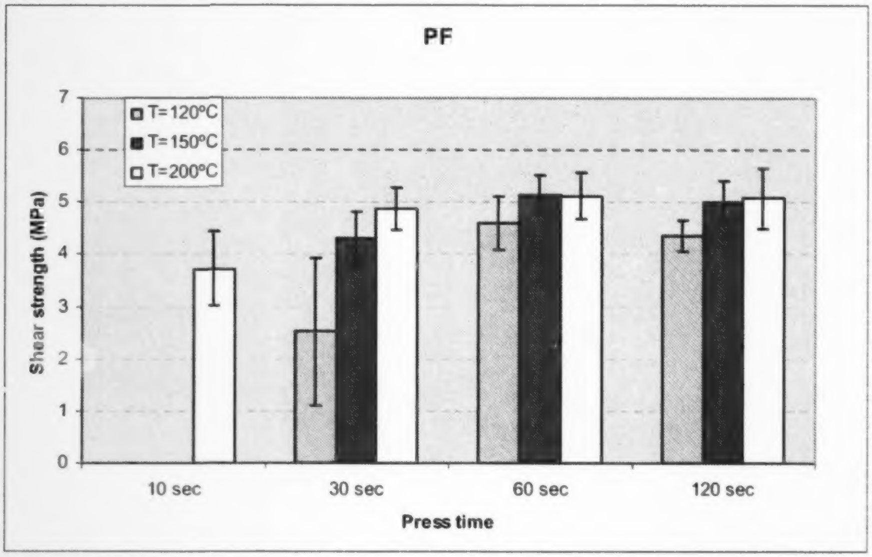


Figure 8. Bond strength of PF adhesive using 20% MC strands.

Shear strength test results for 30% MC strands are shown in Figures 9–12. Final bond strength for all adhesives did not decrease after the MC increased to 30%. This does not mean that all tested adhesives gave good bonding performance for wet strands, but that at high press temperatures and with long press times, most of the moisture probably evaporated during the bonding process.

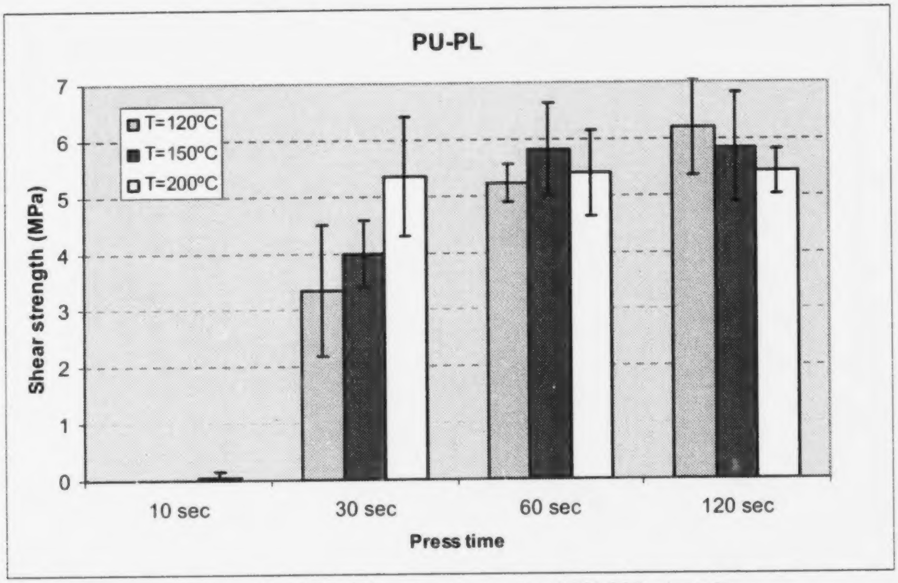


Figure 9. Bond strength of PU-PL adhesive using 30% MC strands.

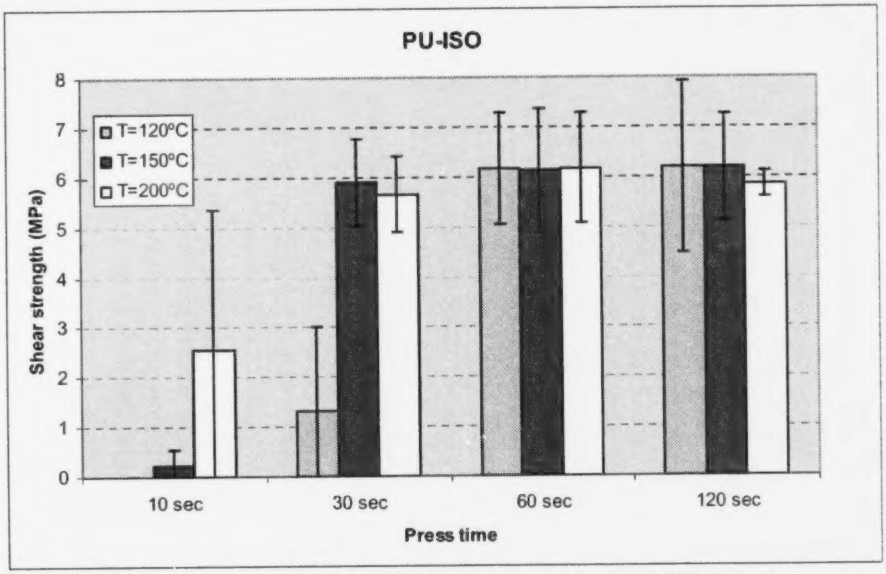


Figure 10. Bond strength of PU-ISO adhesive using 30% MC strands.

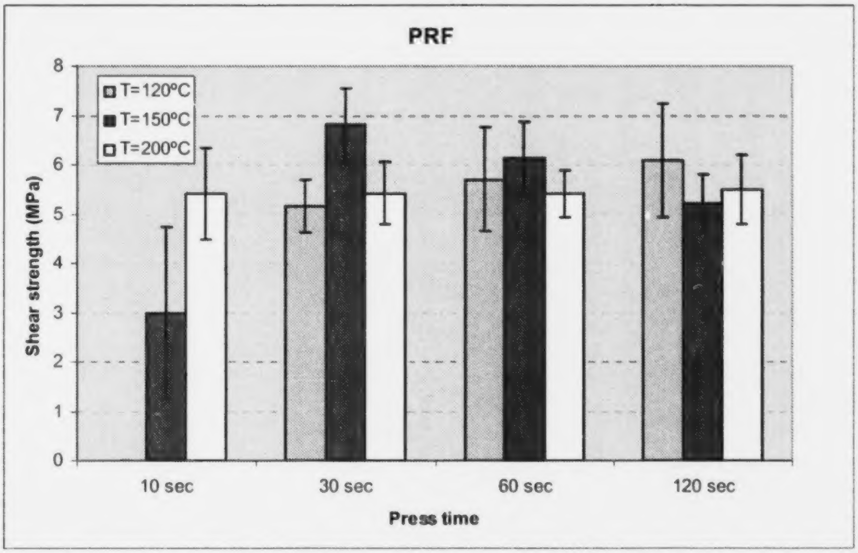


Figure 11. Bond strength of PRF adhesive using 30% MC strands.

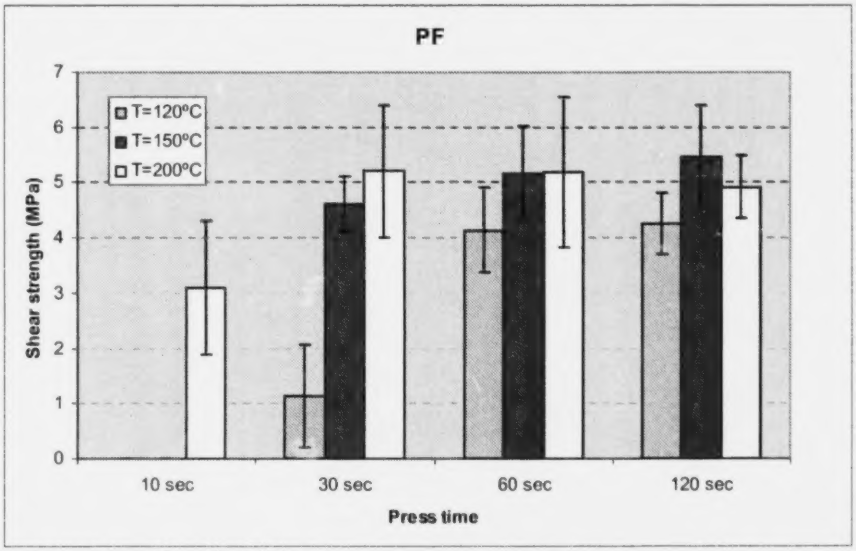


Figure 12. Bond strength of PF adhesive using 30% MC strands.

With the short press time, most resins gave slightly decreased bond strength, particularly at low press temperatures. These results indicate that the bonding performance was affected by MC. As it is shown, however, the bond strength for all adhesives remained almost unchanged even with the short press time at high press temperatures. Again, the reason is that most of the moisture has easily escaped from the thin strands at the high press temperature. This may not occur during green-veneer composing because of the higher veneer thickness.

Figures 13–16 show the testing results of shear strength for 45% MC strands. It is clear that the high MC made significant differences in shear-bond strength among these adhesives. The PU-ISO resin produced outstanding bond strength at both 150°C and 200°C and with the press time shortened to 30 s. The PU-PL

resin gave good bond strength around 5 MPa for the long press times of 60 s and 120 s, but low bond strength for the short press times. Both the PRF and PF resins, however, produced low bond strength in most conditions, even at high press temperatures and with long press times.

These results demonstrate that, of the four selected adhesives, the PU-ISO resin is the best for green-veneer composing. This resin gave the highest bond strength, the highest curing speed and the highest moisture tolerance. The bonding performance of this resin was significantly affected by press temperature, and the resin performed well at both 150°C and 200°C. The PU-PL resin showed good moisture tolerance, but the bond strength and curing speed were lower compared to the PU-ISO resin. The PRF resin showed excellent curing speed and good bond strength, but low moisture tolerance. The PF resin also gave good bond strength and curing speed, but low moisture tolerance.

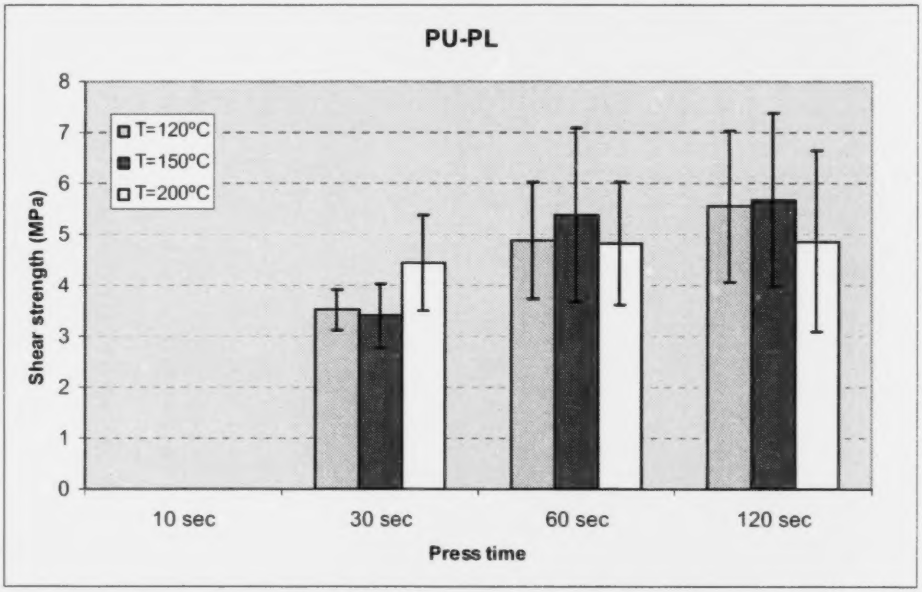


Figure 13. Bond strength of PU-PL adhesive using 45% MC strands.

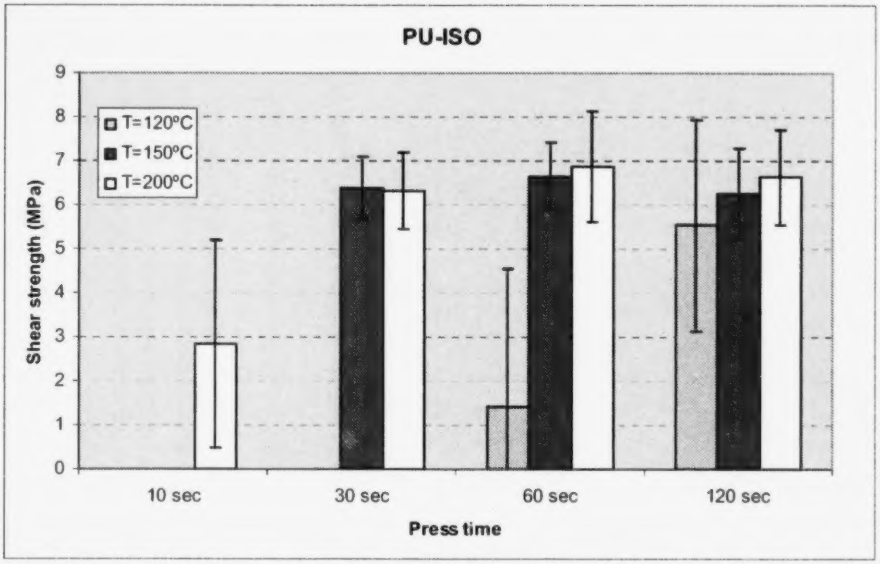


Figure 14. Bond strength of PU-ISO adhesive using 45% MC strands.

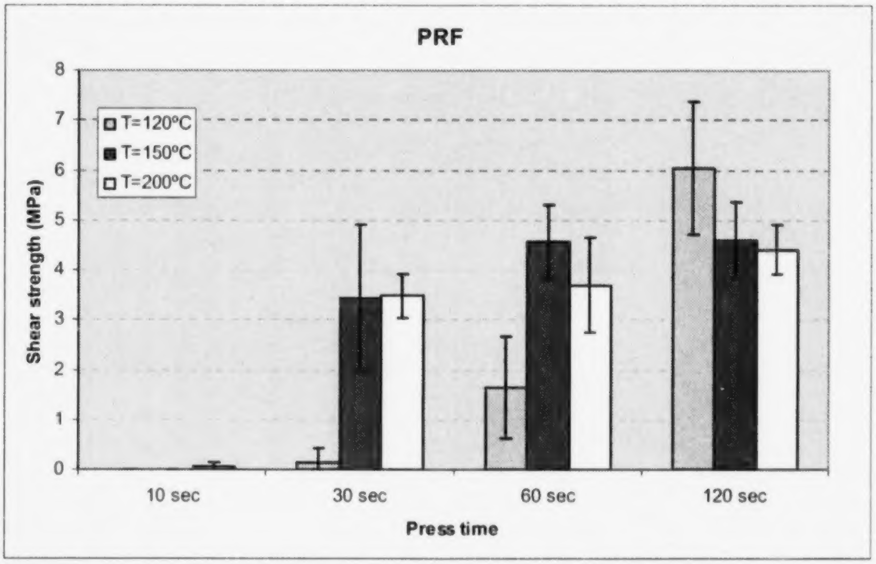


Figure 15. Bond strength of PRF adhesive using 45% MC strands.

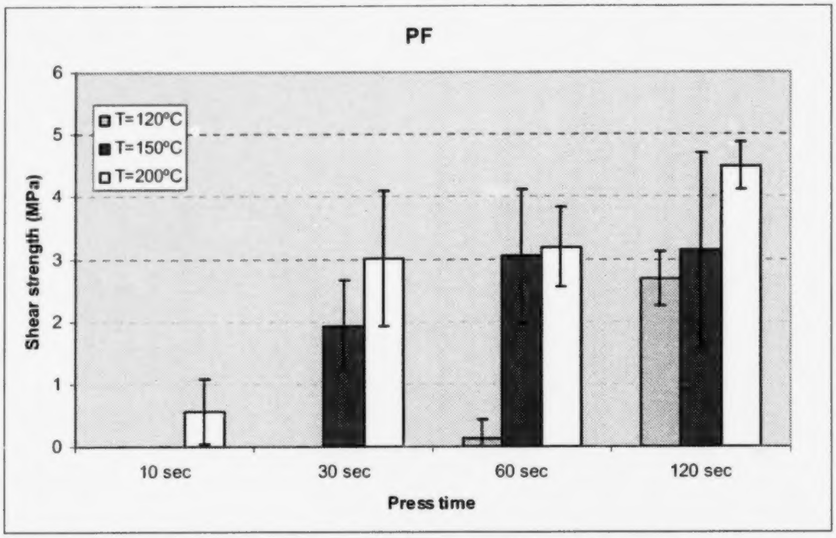


Figure 16. Bond strength of PF adhesive using 45% MC strands.

4.2 Veneer Composing by Gluing

Because tension strength of veneer perpendicular to the grain direction is usually low and varies significantly, it is a poor indicator of the quality of veneer composing. Instead, each veneer composition technology was evaluated using a separate set of criteria.

Veneer composing by taping

In veneer composing by taping, wood failure and glueline failure can occur in the tensile test (Figure 17). Wood failure means the bond strength of the composing tape was high enough to meet the requirement of veneer composing. A composed veneer sample was considered successful if wood failure occurred. This method was then considered feasible if at least four of the five samples were successful.

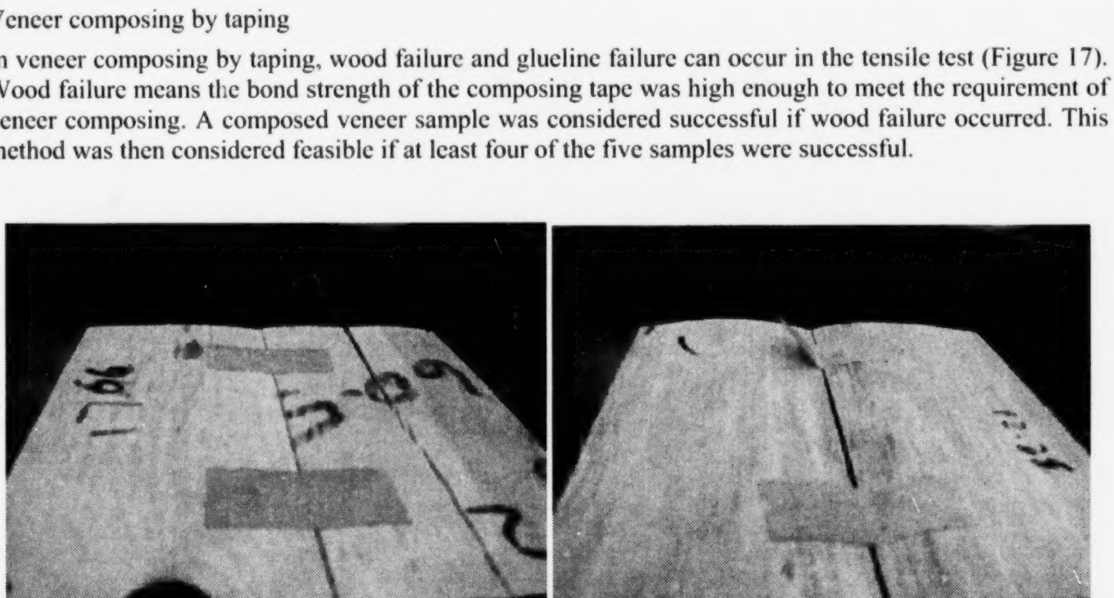


Figure 17. Failure types of composed veneers by taping in tensile test (L: wood failure; R: glueline failure).

Table 2. Test results for veneer composing by taping.

Veneer MC (%)	Glue level on tape (g/m^2)	Number of wood failure/glue failure
20	100	5/0
	150	5/0
	200	5/0
40	100	5/0
	150	4/1
	200	1/4
60	100	4/1
	150	2/3
	200	0/5

Veneer composing by taping was feasible at 20% veneer MC regardless of the level of resin applied, because all tested samples had wood failure (Table 2). At a veneer MC of 40%, veneer composing by taping was considered feasible at glue levels of 100 and 150 g/m^2, but it was not feasible at a high glue level of 200 g/m^2 because four out of five samples failed in the glueline. At 60% veneer MC, veneer composing by taping would be feasible only at a glue level of 100 g/m^2.

Veneer composing by taping became more difficult with increasing MC, due to the incomplete resin cure. As discussed in the section of adhesive screening, the PU-PL resin showed good moisture tolerance, but cured slowly. At high MC and with short press time, the limited heat was absorbed more by the moisture and less by the glue, leading to incomplete resin cure and poor bond strength. High glue levels also impeded veneer composing as excess glue also absorbed more heat and impeded heat transfer to the glue-wood interface.

4.2.1 Veneer composing by string-gluing

Tensile tests of veneer composing by string-gluing had two types of failure: string breakage and string peeling (Figure 18). If string broke in the tensile test, the bond strength was considered sufficient and the composed sample was successful. If at least four of the five samples were successful, this method was considered feasible.

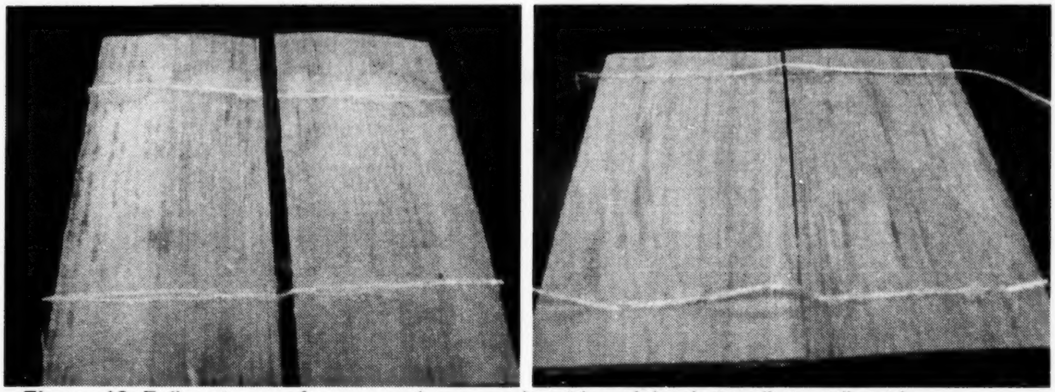


Figure 18. Failure types of composed veneers by string-gluing in tensile test (L: string breakage; R: string peeling).

At a veneer MC of 20%, all composed samples successfully passed the tensile test for both 5 and 10 s press time at 170°C (Table 3). At 40% MC, all composed samples were successful with 10 s press time at 170°C, but two out of five samples were not successfully composed with 5 s press time. At a MC of 60%, the string-gluing method was considered feasible only for the 10 s press time at 170°C.

Table 3. Test results for veneer composing by string-gluing (Press temperature: 170°C).

Veneer MC (%)	Press time (s)	Number of string breakage/string peeling
20	5	5/0
	10	5/0
40	5	3/2
	10	5/0
60	5	1/4
	10	4/1

Veneer MC had a similar effect on veneer composing by taping and on veneer composing by string-gluing. High MC veneers absorbed more heat and reduced curing speed of resins, causing incomplete resin cure. However, the press time of 15 s for veneer composing by taping was decreased to 5 and 10 s for veneer composing by string-gluing at 170°C with the same success for both methods. This difference was due to the use of the faster PU-ISO resin in the veneer composing by string-gluing, and the use of the slower PU-PL resin in the veneer composing by taping. In terms of the productivity of veneer composing by gluing, a short press time is preferred.

4.2.2 *Veneer composing by fibre-gluing*

Failure types for veneer composing by fibre-gluing were the same as for the taping method: wood failure and glueline failure (Figure19). Again, wood failure indicated the composed sample passed, and if at least four of the five samples succeeded, this method was considered feasible.

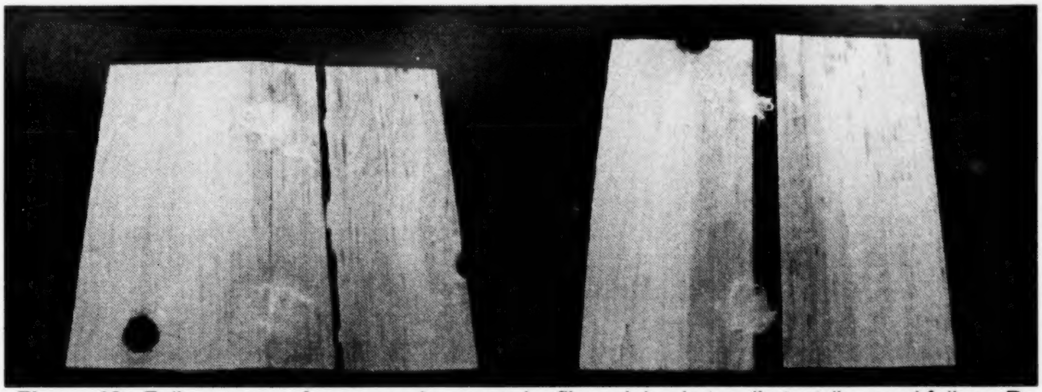


Figure 19. Failure types of composed veneers by fibre-gluing in tensile test (L: wood failure; R: glueline failure).

Veneer composing by fibre-gluing was successful at 20% MC (Table 4). No samples failed in the glueline no matter how much glass fibre was added to the resin within the experimental range. At 40% MC, fibre-gluing was still considered feasible, but one out of five samples failed in the glueline at all fibre contents. At 60% MC, the method was not feasible at any fibre contents. Fibre content did not significantly affect the performance of composed veneers below 40% MC, but high fibre content decreased the bond strength and resulted in more composed samples failed in the glueline at the high MC of 60%.

Table 4. Test results for veneer composing by fibre-gluing (press temperature: at 170°C).

Veneer MC (%)	Fibre content in resin (%)	Number of wood failure/glue failure
20	2	5/0
	5	5/0
	10	5/0
40	2	4/1
	5	4/1
	10	4/1
60	2	3/2
	5	1/4
	10	0/5

Fibre-gluing was less successful than string-gluing for the same press time of 10 s at 170°C as the MC level increased. This suggests that the resin drop used in fibre-gluing needed more press time than the resin coated on string for string-gluing, as the same resin was used in both methods.

4.3 Drying of Composed Veneers

The low and high MC veneers composed by gluing were dried at 180°C to 0%–2% MC. The drying time was 30 min for the composed veneers with 20% MC, and 45 min for the veneers with 60% MC. The high-temperature drying did not affect their bonding performance, but it did shrink them, creating a gap between the two composed pieces.

Shrink percentage and gap size after drying are listed in Table 5. As expected, veneers with higher MC shrunk more. String-gluing yielded veneer with wider gaps than did taping and fibre-gluing, possibly due to the extension of string after drying. Error in gap measurement was high due to the rough edge of veneers. More work is required to minimize this gap because it may affect the quality of composed veneers.

Table 5. Shrink percentage and gap size between composed veneers after drying.

Method	Taping		String-gluing		Fibre-gluing	
MC (%)	60	20	60	20	60	20
Shrink percentage in width (%)	7.43	5.37	7.65	5.16	7.06	5.3
Standard deviation	0.82	0.96	0.37	0.71	0.57	0.82
Gap size between veneers (mm)	<2		2-4		<1.5	

4.4 Economic Analysis

There is up to 30% veneer loss if MPB grey stage logs are used in plywood mills. This loss, which represents an estimated $6 million in annual revenue in a typical plant, can be reduced to $2 million by recovering 20% veneer through green veneer composing. Additional savings in energy and labour are estimated at $0.5 million annually. The total revenue savings are about $4.5 million per year for an average size plant.

Green-veneer composing differs from conventional-veneer composing only in the use of thermosetting resins with one or two components, instead of hot-melt adhesives. Therefore, conventional composing equipment can be used for green veneer composing with a modification to the glue-application system. This requires minimal capital cost. The polyurethane adhesives used in green-veneer composing are generally more expensive than the hot-melt adhesives used in conventional-veneer composing, but the amount of adhesive used for one composed veneer is estimated at only about 5 g. The cost increase in adhesive is insignificant.

5 Conclusions

Adhesive screening using the ABES machine indicated that the PU-ISO adhesive performed best among the four tested adhesives. This adhesive gave the highest bond strength, the highest curing speed and the highest moisture tolerance. The PU-PL adhesive also showed relatively high moisture tolerance, but with lower bond strength and curing speed than the PU-ISO adhesive.

In general, it is possible to compose green veneer by gluing. Taping with the PU-PL adhesive was successful with MC up to 60%—in this case, veneer was pressed for 15 s at 170°C to ensure the resin cured for enough bond strength. String-gluing veneer with the PU-ISO adhesive was also successful with MC up to 60%, but with a shorter press time of 10 s at 170°C. Fibre-gluing was successful with MC up to 40% and with 10 s press time at 170°C.

After drying, the gap between shrunken composed veneers was up to 2 mm for those composed by taping and fibre-gluing, and over 2 mm by string-gluing. Gaps may affect the quality of composed veneers. More work needs to be done to solve this problem.

Preliminary economic analysis indicated that the green-veneer composing may lead to 20% improvement in MPB-veneer recovery, improved drying efficiency, and labour savings, a total saving of $4.5 million per year for an average mill. Mills can implement this technology by using existing dry veneer composers with minimum modification and thus minimum capital investment.

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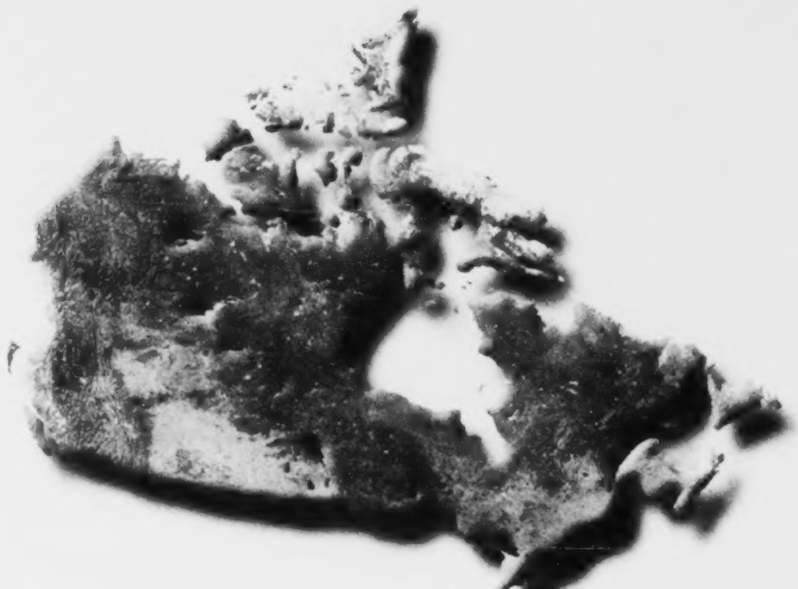

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